Suspended sediments-discharge hysteresis during rainfall events in a small headwater catchment in the NW Spain

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1. Abstract

The relation between SS concentration and discharge is not normally homogenous during the event, often producing hysteretic loops. In this work we identify the hysteresis types of the discharge-SS concentration relationships of four single rainfall events produced at differences times of the year and the relationships between the hysteretic loops and the associated source areas. For this study a rural catchment, located in the NW of Spain, with an area of 16 km^2 was selected. Land use is agroforestry and it is draining by a small stream. Significant variations in the concentration and sediment load have been found between events. Relationship between discharge and suspended sediment concentrations during all events is characterized by clockwise or positive hysteresis. Suspended sediment was higher at a given discharge on the rising limb of hydrograph than at the same discharge on the falling limb. Visual observations made within the catchment allowed to relate these hysteresis loops with sources close to the stream, constituting the rills and ephemeral gullies the main sediment sources.

2. Introduction

The determination of particulate source and delivery processes, in turn, relies on an understanding of complex transport dynamics over many time-scales (Kronvang et al., 1997). Sediment delivery is highly episodic, and extreme flood events can result in sediment loads several orders of magnitude larger than yearly averages. The delivery of suspended sediment and water may be asynchronous giving rise to hysteresis effects, i.e. different sediment concentrations for discharges of equivalent magnitude on rising and falling limbs of a hydrograph (Beschta, 1987;Gurnell, 1987; Kronvang et al., 1997). Hysteresis effects have been used for identifying different runoff and erosion types (Seeger et al., 2004), sediment delivery, and source area (Piest et al., 1975; Klein, 1984; diCenzo and Luck, 1997; Williams 1989) identified five possible forms of hysteretic curves. The most common hysteresis relationship is the clockwise. This pattern has been attributed to the flushing and subsequent exhaustion of sediment from channel or nearby sources prior to the discharge peak (e.g., Baca 2002; Slattery et al. 2002;Lefrançois et al., 2007). However, Steegen et al. (2000) suggested that clockwise hysteresis was produced not by sediment flushing and exhaustion, but by the supply of sediment from distant hillslope sources, which are usually associated with counter-clockwise curves (Klein, 1984; Goodwin et al., 2003). Other interpretations include higher rainfall intensities at the beginning of storms and a reduction in the erosive effects of rainfall (Doty and Carter, 1965) and increased inputs from baseflow after the peak discharge (Wood, 1977; Baca 2002), the interval between events (Wood, 1977) the duration of the event (Wood, 1977), as well as the development of a gully network (diCenzo and Luck, 1997).The disparity of interpretations of hysteretic loops, it makes that these can not be used as unique tool for identification sediment sources. For this reason it is necessary to obtain direct information on sediment sources and erosion processes in the catchment.

The purpose of this study was to a) identify the hysteresis types of the discharge-SS concentration relationships of four single rainfall events with differences in discharge, sediment transport and rainfall conditions, and b) to analyze the relationships between the hysteretic loops and the associated source areas at catchment scale. Measurements of discharge and suspended sediment at the catchment outlet have been carried out. In addition visual observations were made within the catchment after each rainfall event, in order to identify possible sediment sources.

3. Methods

This study was conduced in the Corbeira, a headwater of the Mero River, located in the NW Spain. The catchment has an area of 16 Km^2. The underlying geology of the catchment is basic schist. The altitude varies between 60 and 474 m, the mean slope is 19% and maximum slope is more than 55%. The predominant soils are Umbrisol and Cambisol, based on the FAO (2006) with silt and silt-loam texture. Around 65% of the catchment is forested. Agriculture areas are mainly covered by grassland, pasture and maize. The major part of agricultural fields bordering the stream is covered by pasture and only found crop maize surrounding the stream in the upper catchment. The climatic conditions are typical of a temperate oceanic environment. The mean annual precipitation is 1024 mm (1985-2005) mostly concentrated from October to March and the rain intensity is moderate.

Discharge (Q) was measured continually at the outlet catchment, using a pressure sensor and rating curve methodology. Water samples were collect using an automatic sampler (ISCO 6712FS). The sampling interval during rainfall events was variable, depending on the rate of change of discharge on the rising and falling limbs of the hydrograph. Suspended sediment concentration (SSC) was determined using the gravimetric method. Suspended sediment load was calculated from the SS concentrations and discharge data. When rills and gullies occurred within the catchment, we calculated the weight of soil eroded and deposited within it. The difference between the two provided the sediment delivery to the stream.

To classify the events in relation to their hysteretic loop, discharge-SS graphs were drawn with linear axes for both variables.

4. Results

The characteristics of events are summarized in table 1. There are considerable differences in the variables of both precipitation and discharge, as in SSC and suspended sediment load. Peak suspended sediment concentration during the events ranged from 42 to 530 mg/L and the load between 0.3 and 7.6 t. For example, the event of 19-20 Oct, produced with 47.4 mm of rainfall, when the initial discharge (Qin) was 45.4 L/s, reached a discharge of 366.8 L/s, a SSC of 111 mg/L and generated a load of 0.8 t. However, the event of 28-30 Dec, which was produced with less rainfall than the last, but with more antecedent moisture and more initial discharge, reached a SSC of 530 mg/L and a load of 7.6 t, values much higher than the rest of studied events. During the event 28-30 Dec 2004 rills and ephemeral gullies were developed in the head catchment, in a ploughed field next to the stream. These caused a sediment delivery to the stream of 6.9 t. The load of SS in this event slightly exceeded the quantity of exported sediment from rills and gullies, suggesting that these were the main source of sediment in this event, which agrees with the results of other authors (diCenzo and Luck, 1997; Piest et al., 1975; Steegen et al., 2000)

Table 1 Event data for Corbeira catchment during four events.

Event date and duration (h)	Precipitation variables			Discharge variables		Suspended sediment variables		Hysteresis direction
	P total (mm)	AP3 (mm)	AP5 (mm)	Qin (L/s)	Qmax (L/s)	SSCmax (mg/L)	SS load (t)	
28-30 Dec. 04 (37)	22.0	27.2	31.0	170.2	580.3	530	7.6	**C**
26-28 Mar. 05 (43)	18.8	12.6	24.4	280.3	476.3	141	3.3	**C**
2 May 05 (8.5)	3.8	1.8	1.8	323.6	382.7	42	0.3	**C**
19-20 Oct. 05 (47)	**47.4**	**9.8**	**18.2**	**45.4**	**366.8**	**111**	**0.8**	**C**

AP3: antecedent 3 day rainfall, AP5: antecedent 5 day rainfall, C: clockwise hysteresis.

In spite of substantial differences in discharge, sediment transport and rainfall conditions between events, we only identified one type of Q-SSC hysteretic loops. Relationship Q-SSC is characterized by clockwise or positive hysteresis, with suspended sediment peak leading hydrograph peak. This behaviour is shown in figure 1.This figure shows that there is a steep increase in sediment concentrations with increasing discharge especially for events of highest suspended sediment load. These positives hysteresis have been explained in several ways as has been previously indicated. Thus, these forms were linked with the event conditions, with the sediment sources, etc. (Klein, 1984, Williams 1989). In our case, field evidences allow to attribute the occurrence of clockwise hysteresis to the rapid displacement of sediment from source close to the stream or within this. The sediment availability was highest when soil surface was not protected by vegetation. Thus, as noted above rills and ephemeral gullies were the main sediment sources in the catchment.

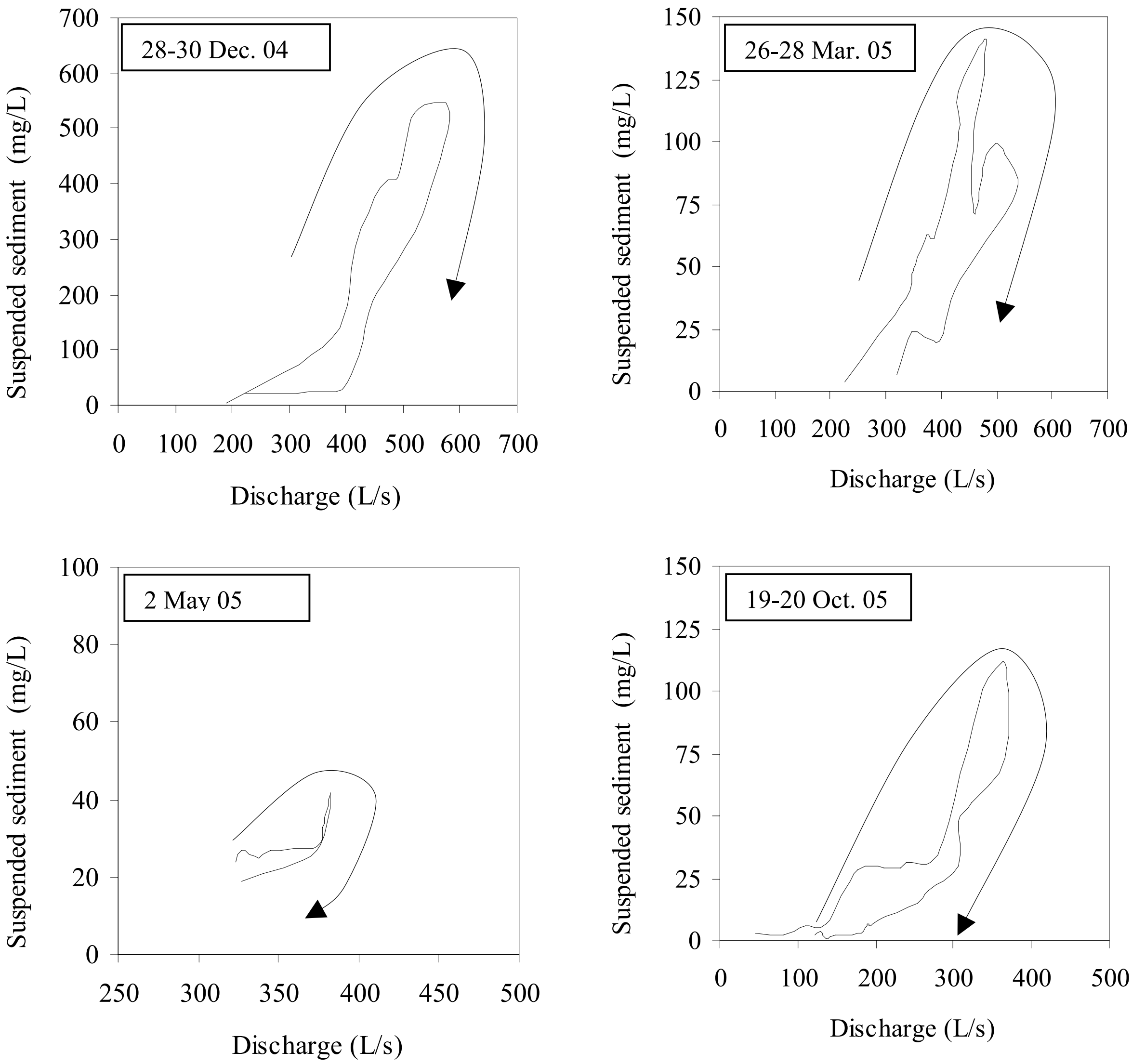

Figure 1 Clockwise hysteresis loop showing the trend of the discharge/ suspended sediment concentration relationship for the studied events.

4. Conclusions

The results of this study reveal that the relationship between discharge and suspended sediment concentration is characterized by clockwise hysteresis, despite the great differences between the events, i.e. differences in terms of pre-event and event. This positive hysteresis could indicate the existence of suspended sediment sources near to the stream, which has been verified by visual observations made within the catchment.

This study shows the importance of rills and ephemeral gullies, located in areas close to the stream, in the suspended sediment exportation from the catchment.

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